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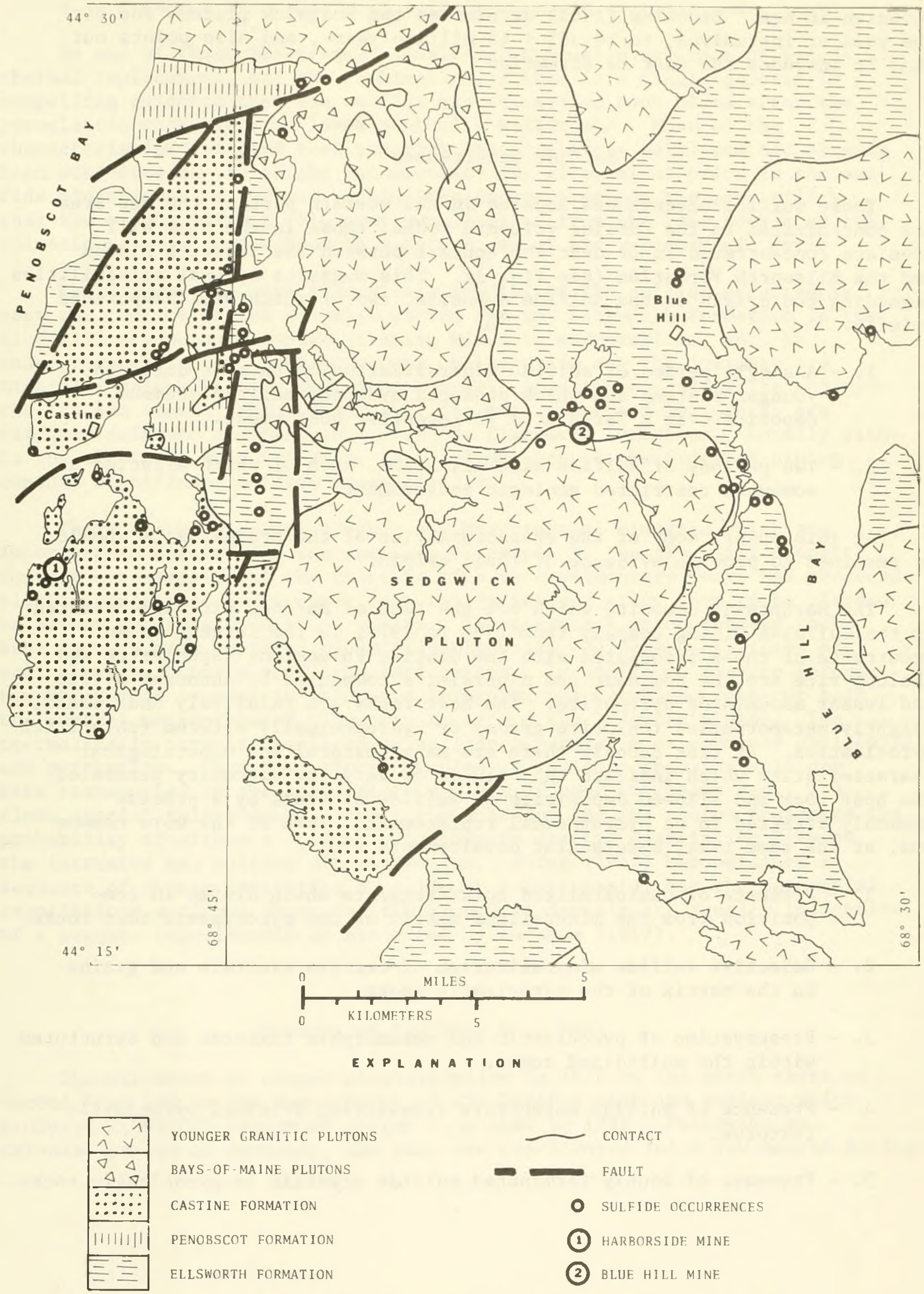
Introduction

The Penobscot peninsula, which lies between Penobscot Bay and Blue Hill Bay, is underlain by schists, volcanic rocks and intrusive rocks (see fig. 1). The Ellsworth Formation, which is dominant in the eastern part of the area, is a heterogeneous sequence of interlayered pyroclastic rocks, flows and clastic sedimentary rocks which have been highly deformed and metamorphosed to chlorite or biotite grade. At some localities original bedding features have been preserved, but more commonly the primary characteristics have been obliterated. Typically the rocks of the Ellsworth Formation contain abundant oriented chlorite or biotite resulting in a strong foliation. Colors range from light gray or greenish gray to almost black, depending on the relative abundance of quartz and feldspar as compared to the abundant chlorite and biotite. Segregations of quartz-rich zones are commonly present parallel to the foliation resulting in banded structures. Interbedded with the highly contorted schistose rocks are quartzite units as much as 300 feet thick which have reacted competently to the deformation.

The Castine Formation which dominates the western part of the area is composed of volcanic rocks including pillow basalts, felsic to intermediate tuffs and rhyolitic breccias, and less commonly slates and phyllites. The great variation in lithology has made stratigraphic correlation, even on a local scale very difficult, and as a result the total thickness and regional stratigraphy have been difficult to assess. The rocks have been subjected to chlorite grade metamorphism, but characteristically the original textures, especially of the coarser pyroclastic rocks have been preserved. Brookins et al. (1973) have established the age of the Castine volcanic rocks as 390 $\pm$ 5 million years.

The intrusive rocks of the area include gabbro and diorite of the Bays-of-Maine complex (Emmons, 1910; Chapman, 1962; Cheney, 1969), and the younger plutons most recently described by Chapman (1968) and Wones (1974). The younger plutons which show a close spatial relationship to many sulfide occurrences are characteristically granite or quartz-monzonite which vary in texture from coarsely porphyritic to fine-grained equigranular. They exhibit sharp discordant contacts not only with the Ellsworth and Castine Formations, but also intrude the rocks of the Bays-of-Maine complex. Commonly the intruded rocks have been brecciated, and the dislocated blocks have been engulfed and assimilated to varying degrees by the felsic plutons. Where the younger plutons invade the Ellsworth Formation, extensive metamorphic aureoles have resulted. The most common effect of metamorphism is the formation of hornfels containing biotite and cordierite as the characteristic minerals. Faul (1963) has determined the younger plutons to be early Late



Geology Modified from Brookins et al. (1973), Chapman (1968) and Cheney (1969)

FIGURE 1. GENERALIZED GEOLOGIC MAP OF THE BLUE HILL - CASTINE AREA

Devonian in age. Brookins (1968) determined the Sedgwick pluton, one of the younger intrusives, to be 395 $\pm$ 15 million years, and also points out that it intrudes the Castine Formation.

Sulfide Occurrences

Those sulfide occurrences located in the western part of the map area are concentrated in the Castine volcanic rocks; those in the Blue Hill area are concentrated at or near the contact between the Sedgwick pluton and the Ellsworth Formation (see fig. 1). This suggests several possibilities regarding the origin of the sulfide deposits, two of which will be pursued briefly.

1. - A single period of sulfide mineralization which post-dated the younger plutons and which produced hydrothermal replacement deposits over a large area in receptive host rocks.

2. - Two periods of sulfide mineralization, each of which affected a somewhat restricted geologic environment.

At this point, some of the characteristics of the ore deposits should be examined to provide evidence of their origin.

The Harborside deposit, which was the site of an open pit mine operated by the Callahan Mining Company from 1968 to 1972, is the largest known occurrence of those associated with the Castine Formation. Sphalerite and chalcopyrite are the dominant ore minerals, accompanied by abundant pyrite and lesser amounts of pyrrhotite. The host rocks are relatively undeformed, slightly metamorphosed (chlorite grade) or hydrothermally altered (chloritic) pyroclastics. At that deposit there are many textural and mineralogical characteristics which indicate that fluids of very low viscosity permeated the host rock and allowed deposition of sulfide minerals by a process commonly referred to as hydrothermal replacement. Some of the more common and, at the same time, spectacular developments are:

1. - Presence of unmineralized rock fragments which differ in composition from the mineralized matrix of the pyroclastic host rocks.

2. - Selective sulfide mineralization of certain minerals and grains in the matrix of the pyroclastic rocks.

3. - Preservation of pyroclastic and metamorphic textures and structures within the sulfidized zones.

4. - Presence of sulfide metacrysts transecting original pyroclastic textures.

5. - Presence of doubly terminated sulfide crystals in pyroclastic rocks.

6. - Presence of gradational sulfide mineralization fronts.

No one of these features by itself is conclusive evidence of hydrothermal replacement, but the combination of them in a single deposit is compelling evidence that the sulfide mineralization took place after the pyroclastic rocks were at least partially solidified. Most of the characteristics indicate that the rock was completely solid and had already been subjected to its slight metamorphism (or alteration) prior to the sulfide mineralization. These conclusions do not preclude the possibility that the ore-depositing solutions were derived from the same source as the volcanic material and represent a late stage of the volcanogenic cycle.

The largest and most intensively studied of the sulfide occurrences near the contact of the Sedgwick pluton and the Ellsworth Formation is the Blue Hill ore deposit, which is being mined by Kerramerican, Inc. by underground methods. Sphalerite and chalcopyrite are the dominant ore minerals; galena is rare and of no economic importance, and pyrite and pyrrhotite are common gangue minerals. The most important host rocks are slightly deformed quartzite units of the Ellsworth Formation. Locally within the mine area thin (25 to 50 feet) off-shoots of the Sedgwick pluton contain significant sulfide mineralization.

There are several metamorphic and hydrothermal minerals which are important in determining the sequence of events in the Blue Hill deposit. Contact metamorphism of the chlorite rich metasedimentary rocks has produced biotite-cordierite rocks whose textural variations allow them to be classed as either hornfels, schist or gneiss. These contact metamorphosed rocks have in turn been replaced by sulfide minerals; replacement textures are well shown by biotite-sulfide relationships. In addition, dravite (brown tourmaline) is present in veins and irregular masses which cross-cut both the contact metamorphosed Ellsworth rocks and the Sedgwick pluton. The tourmaline in turn is replaced by sulfide minerals, most commonly chalcopyrite and pyrrhotite. These relationships clearly indicate that the sulfides were transported in the ionic state and are of post-intrusive age. The close spatial relationship between the sulfides and the pluton indicates the probability of either a collinear or cognate genetic association between the intrusive and sulfide mineralization. Ching (1942) has outlined a sequence of events indicating a collinear relationship, but the sequential associations outlined above for the Blue Hill deposit are equally indicative of a cognate relationship as described by Burnham (1967).

History of the Blue Hill Mine

The discovery of copper mineralization in 1876 on the north shore of Second Pond led to the development of the Douglas mine and smelter which produced 2,000,000 pounds of copper from 1880 to 1884. Following an extended period of dormancy, the mine was reactivated for a few months during

World War I, but could not survive the low market price of copper. Another period of quiescence preceded an attempt by the U.S. Bureau of Mines to delineate an eastward extension of mineralization in 1948 by drilling seven exploratory holes. Lack of sulfide intercepts discouraged further work at that time.

Recent exploration began in 1957 when Texas Gulf Sulphur instigated a drilling program which resulted in the discovery of significant copper and zinc mineralization directly beneath Second Pond and slightly to the southwest. Black Hawk Mining Company, a subsidiary of Denison Mines, Ltd. then entered the scene and pursued those discoveries with additional drilling through the early 1960's. Encouraged by the results of their drilling project, Black Hawk expanded their efforts by sinking a shaft in 1964 and 1965. The three-compartment shaft reached a depth of 698 feet, with development levels at 380, 480 and 580 feet. Black Hawk completed approximately 10,000 feet of lateral development on those three levels and in addition drilled 31,750 feet of core from the underground workings. The company experienced difficulty in holding experienced miners with the project and as a result also found it difficult to keep the development with the ore. Early in 1967 Black Hawk Mining Co. suspended operations and permitted the underground workings to become flooded.

In 1970 Keradamex, Inc., a wholly-owned American subsidiary of Kerr Addison Mines, Ltd., entered into an option agreement with Black Hawk Mining Co. for the development of and production from the Black Hawk mine. After completing a drilling program to test a geologic theory of continuity of ore mineralization, Kerradamex exercised the option in mid-1971. By agreement, Kerramerican, Inc. (another subsidiory of Kerr Addison established to mine this property) was to acquire a 60% interest in the property after producing 500 tons of ore per day by September 1, 1973. Construction and pre-development began in July 1971 and in September of that year a 15% decline ramp was started in order to provide trackless access from the surface to the ore horizons. Once the ore zones were reached, a trackless pilot and slash technique was used for mining. Two rubber-tired jumbos were used for drilling, and broken ore was loaded into dump trucks for transportation to the crusher or stockpile at the surface. Kerramerican met their production objective as outlined in the agreement with Black Hawk Mining Co., and now are completely responsible for the mining and milling operation.

Mine Geology

The Second Pond mineralized area is underlain by the Ellsworth Formation which has been intruded and contact metamorphosed by the Sedgwick pluton. That portion of the Ellsworth Formation which is present in the mine area can be subdivided into four lithologic units which are described briefly in Table 1.

TABLE 1. Subdivisions of the Ellsworth Formation in the Blue Hill Mine.

Unit	Thickness	Description
Allen quartzite	greater than 300 feet	Massive to banded, brownish-gray to purplish-gray biotite-cordierite quartzite; variation in color and foliation dependent on amounts of dark brown biotite and blue-gray cordierite each of which may range in content from near zero to 40%; gradational into underlying schist with increase in biotite content. (Originally this quartzite was considered two units, Allen quartzite and Robbins quartzite, but is now treated by Kerramerican as a single unit).
Biotite schist	100 to 500 feet	Foliated, crenulated brownish-black to purplish-black biotite schist; biotite is dominant (up to 85%), blue-gray cordierite porphyroblasts are common in some areas, absent in others, quartzite content is variable and inversely related to the biotite content.
Pond quartzite	150 to 300 feet	Massive, gray quartzite with minor biotite and sericite; generally lacks prominent foliation and recognizable bedding; host for most of the known ore deposits.
Banded quartzite	150 to 250 feet	Upper portion dominated by alternating brownish-black biotite rich layers and dark green chloritic quartzites; quartzite dominates the lower portion and resembles the Allen quartzite, with the exception of the chlorite content.

The most common effect of metamorphism by the intrusive is the transformation of chlorite to biotite. In certain stratigraphic horizons where the mineralogy is suitable and where heat has been sufficient, cordierite porphyroblasts have developed and have produced a rock with a gneissic texture. Biotite and cordierite are not characteristic of the Ellsworth Formation except near the intrusive contacts.

In addition to the mineralogical change, a hybrid breccia zone has been formed irregularly at the contact. It is composed of partially assimilated blocks of Ellsworth Formation surrounded by granitic material. Both the mineralogical and intrusive breccia effects form zones as much as several hundred feet thick.

Although the Sedgwick pluton has a relatively narrow range in mineralogical composition (granite to quartz monzonite), the texture varies from fine-grained to coarse-grained and porphyritic, and the color varies from light gray to blue-gray, green and tan-orange. The color variations are primarily due to feldspar hue; although there is a wide range in the biotite content, its effect is to lighten or darken the colors. The pluton tends to be concordant and sill-like, generally located above the Pond quartzite. Within the mine area the thickness of the pluton is variable, attaining a maximum of 200 feet and increasing in thickness toward the south. There are many localities near the contact where the pluton has been partially to almost completely replaced by sulfide minerals. To complicate matters, there are also a few localities where unmineralized apophyses of the pluton cut across sulfide zones in the Ellsworth Formation.

A significant thickness of dark green, medium-grained gabbro is associated with the Sedgwick pluton southwest of the mine area. Within the mine, however, only minor (10 feet or less) gabbro or diabase dikes occur. All observed gabbro occurrences in the mine are pre-ore in age, and presumably part of the Bays-of-Maine igneous complex.

Ore deposits

The ore mineralization is related to the axis of an open syncline in the Ellsworth Formation striking N 30°W and plunging 30°SE. Mine development and geologic studies have disclosed a significant wrinkling in the axial plane of the syncline which may have resulted from drag folding or superimposition of a second generation fold. The Ellsworth Formation and banded ore deposits commonly contain folds with amplitudes of 10 to 20 feet. Several folds of large magnitude have been observed and interpreted to be distorted drag folds parallel to the major fold. Interpretation of surface drilling indicates a flattening of the major syncline down plunge, but data are sparse and details of the structural trends are not well known.

Several faults which are locally significant have been recognized on the mine property. The Mammoth fault was first detected by Black Hawk Mining Company as a result of surface drilling and has been further defined by Kerramerican drilling. Early in 1974 the fault was crossed by the Mammoth haulage drive, substantiating its projected position. New movement on the fault is estimated to be 100 to 200 feet in a reverse direction.

The Carleton fault was outlined by Kerramerican geologists on the basis of drill hole intersections which show planar continuity. The throw on the Carleton fault is estimated to be 100 feet or less in a reverse direction.

The Sedgwick and West faults, which are cross-faults between the Carleton and Mammoth faults, were first detected in drill hole intersections. The West fault has been substantiated by mine development, and the Sedgwick fault is now interpreted to be a locally sheared monoclinal fold.

The Dam fault is the only one of significance recognized in an ore body. It is present in the Second Pond "A" zinc zone where it has a displacement of about 30 feet, and is accompanied by marked thickening of massive sulfides on the hanging wall. The combined accumulation of sphalerite, pyrrhotite, pyrite and chalcopyrite approaching 30 feet is unique in the mine.

The most important ore mineralization at the Blue Hill mine consists of massive sphalerite occurring in at least four strata-bound horizons which are nearly continuous over most of the mine area. The horizon which currently accounts for the greatest production is the Second Pond "A" zinc zone which occurs near the upper contact of the Pond quartzite. The mineralization has local folds and disruptions of sufficient magnitude that in some areas the miners have difficulty staying on the ore. Massive sphalerite of the "A" zone ranges in thickness from less than an inch to over twenty feet, and averages about two and a half feet. The massive sphalerite of the "A" zone contains as much as 3% chalcopyrite and 25% combined pyrite and pyrrhotite; commonly the zone is dominated by gangue sulfides. Disseminated and veinlet sulfide minerals occur throughout the mine area, most commonly near the massive sulfide horizons. Sphalerite is typically coarse-grained, dark brown to almost black; rarely paler shades of brown and fine grained textures occur. Three additional zinc horizons similar to the "A" zone have been discovered by diamond drilling, but ore bodies have not yet been delineated.

Chalcopyrite mineralization is widespread in the mine area, commonly occurring as replacement at intergranular boundaries in quartzitic units. It also occurs in fracture fillings and by replacement in all rock units including the Sedgwick pluton. In spite of the widespread occurrence of chalcopyrite, only two zones are large enough and sufficiently mineralized to be considered orebodies. The Lower Second Pond (L.S.P.) orebody lies directly beneath the "A" zinc zone, at or near the base of the Pond quartzite. Thickness of the L.S.P. orebody ranges from a few feet to 30 feet. The Mammoth area, southwest of Second Pond contains two zones similar to the L.S.P. orebody, but on the basis of current information, only a portion of one of the zones in the lower-middle Pond quartzite can be considered an orebody.

Hydrothermal alteration of host rocks is common but not consistent throughout the mine. A systematic study concerning alteration has not yet been carried out, and at this time the spatial and paragenetic relationships between alteration products and sulfide minerals are not well known. Sericite, chlorite, biotite, amphiboles, tourmaline and green feldspar have been reported as alteration products, but analytical confirmation has been attempted for only a few specimens.

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Itinerary

Discussion of mine geology and tour of underground workings will take place at the Kerramerican Blue Hill mine (about 1½ hour drive from Orono). To reach the Blue Hill mine follow Route 15 from Bangor to Brewer to Bucksport and Blue Hill. Directions from Blue Hill village to the mine are as follows:

Mileage	
0	Blue Hill Post Office at intersection of Route 15 with Routes 172 and 176. Follow 15, 172 and 176 southwest out of town.
0.6	Intersection. Continue straight ahead on 15 and 176.
1.8	Turn left on gravel road at sign "Kerramerican Blue Hill Venture".
2.1	Mill tailings pond on left.
2.2	Second Pond on right.
2.4	Mine gate. Proceed through gate and bear right. Continue to right of concrete block building with mine headframe. Park in lot overlooking Second Pond. Discussion begins at 10 A.M.